MANAGEMENT OF BIOLOGICAL AND CHEMICAL INCIDENTS: SIMULATION-BASED DECISION SUPPORT*

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Decision making processes during biological or chemical incidents represent a challenging and demanding issue. This task is constituted by several complex activities and important decisions. In the case of unintentional accidents in agricultural plants or within related industries, these decisions have to be made by personnel often not primarily trained for such situations. Therefore any available support tool, which can increase the probability of successful management of these incidents, should be employed. The main objective is to minimize the consequences, ensure the quality of products, and protect people and animals and other crucial assets. From the technological perspective, various approaches or principles have already been applied and intended for computer-based support of biological or chemical incidents management. Nevertheless, the multi-agent technologies can be also effectively utilized. As an example, this paper presents a model applicable for the management of biological or chemical incidents created in the multi-agent NetLogo environment. The main contribution to the scientific field includes the characterization of specifics related to the discussed type of decision-making process. Moreover, within the paper the description of the simulation model is provided, parameterization is explained, and areas for further research are outlined.

biological incident management; chemical incident management; decision making; process; multi-agent technologies; simulation modelling

INTRODUCTION

Currently, agriculture and related industries are closely connected with advances in the area of biology and chemistry. Unfortunately, from time to time we have to cope with biological or chemical incidents. These apparently represent a considerable threat for our society and have more serious consequences than ever before. This can be explained by more sophisticated biological agents and chemical compounds, increasing value of endangered assets, and also by fast development of technologies within last few decades. To categorize them, one group covers incidents caused by biological or chemical weapons, while the second is represented by unintentional incidents like the leakage of a dangerous substance from a plant or laboratory, or natural incidence of a disease within animal herds. The intentional incidents are usually easier to manage, because their focal point can be typically quickly identifiable and localized more precisely. Therefore, the critical assets can be recognized faster and adequately protected. The appropriate response to these incidents is conducted only by trained personnel, usually pertaining to police, epidemiological or armed forces. On the other hand, in the case of unintentional accidents, which occur within agricultural mills or plants, people responsible for the management of such complex and difficult tasks are usually not trained enough for prompt and professional decisions which would protect the critical assets. Therefore, the biological and chemical incidents remain a challenging as well as important task for both researchers and practitioners. Considering the afore-mentioned reasons, a tool for decision support and for the improvement of the decision effectiveness and consequences minimization needs to be used. The objective of the present paper is to introduce the multi-agent based simulation, because it provides us with the advantages such as problem complexity elimination, incident scenario modelling, or more effective resource planning and utilization. Moreover, the demands on non-expert decision makers are decreased significantly. It ensures flexible and more precise attitude to the incident management.

MATERIAL AND METHODS

Apparently, the management of biological and chemical incidents represents the unstructured and complex problem. For the purposes of its resolution,

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a vast amount of various real data must be considered. The determination of the appropriate combination of available reactions and suitable countermeasures should be supported by the data on the environment, in which the incident proceeds as well as on the agent, which has spread within the environment (Otčenášková et al., 2011). Therefore, it represents a noticeable potential for a scientific research which should e.g. answer the question how to ensure in certain situations a qualified decision support which would provide relevant output acquisition applicable in practice.

The responsible persons who make crucial decisions and give orders to coordinate the situation are not infallible. Being mostly'managers', usually they are not experts in biology, epidemiology or toxicology. It is well-known that during the decision-making processes they use different criteria than experts in certain domains such as medicine (Kahn et al., 1997) or information technologies (Bureš et al., 2006). Therefore these decisions necessitate support and improvement to ensure higher reliability as well as appropriateness of the actual course of action. For such a task, appropriate modern technologies enabling to find the scenarios describing the incidents development and their simulation. These can enable better resource planning and their more effective utilization together with the minimization of losses and inadequate actions. Likewise, they guarantee faster response to a certain incident and higher accuracy and adequacy of countermeasures. At the general level, the decision making process during the incident management process can be divided into the under-mentioned phases. After the identification of the incident and its description, it is necessary to create the scenarios of its further development. The set of countermeasures which will be realized in practice must be determined after the choice of the most pessimistic, most optimistic, and most probable scenario. The entire system for the decision support based on the simulation of the incident should comprise the following parts:
(1) module for the description of the emerging incident,
(2) module for the creation of potential scenarios of further development,
(3) module for the support of countermeasures selection.

This paper is aimed at the description of the second module, the subsystem supporting the scenario creation in the case of a biological incident, and proposal of appropriate technology utilizable for these purposes. A particular example is mentioned as well.

Simulation in the context of other methods

The idea to use modelling and simulations in biological or chemical incidents has been discussed earlier (Hurd, Kaneene, 1993). The simulation itself represents the examination of characteristics and behaviour of a particular system on the basis of the experiments.

According to Axelrod (2007), there is a mutual relation between the simulation, induction, and deduction. While the induction serves the general knowledge revelation from the specific particularities, the deduction leads to the certain conclusion derivation on the basis of general knowledge. Likewise the deduction, the simulation is based on the set of explicitly given presumptions which however do not lead to the verification of the certain conclusions and unexpected results might arise. Within this context, the simulation results primarily in generation of data which are suitable for further analysis by the induction method. During the biological and chemical incident management, the induction method is utilizable only in the phase focused on the prevention of potential problems. In the case of existing problems it is necessary to utilize the simulation which eliminates the problem complexity and noticeably decreases the demands on decision makers. Furthermore, the scenario development makes it possible to better prepare for the incident consequences thanks to the modelling of a real situation development according to the given parameters. Evidently, it is easier to plan the utilization of the technical, human, time as well as financial resources more effectively.

Agent-based simulation

Biological and chemical incidents can be characterized as coupled human and natural, open, and at least high dynamic systems which include uncertainty. "They manifest various complexities such as heterogeneity, nonlinearity, feedback, and emergence" (An, 2011). Therefore, the application of multi-agent approach is worthy (Olševičová, 2011). Moreover, existing research results support this idea. At the general level, Grimm et al. (2006) developed a protocol for individual-based and agent-based models. At the application level, Dion et al. (2011) used multi-agent simulation for modelling of spatial and temporal dynamics of foot-and-mouth disease in South Africa. Also Linard et al. (2009) used multi-agent model to assess the risk of malaria re-emergence in France.

Currently, the multi-agent approach is successfully used within various fields because of its advantages. Within practice multi-agent technologies are employed in tourism (Čech, Bureš, 2009), for ontology derivation (Iordan et al., 2008) or for improving health care services in terms of increasing the quality and efficiency (Tsai et al., 2010). Moreover, these are successfully used within the business area – for example during the enterprise mobilization, distributed knowledge processing or market simulation providing the analysis and prediction of consumer groups' behaviour. In all these cases, there is a given environment with a lot of actors (agents) who bear specific characteristics and who behave in a certain way. During the afore-mentioned complicated processes, a lot of miscellaneous influential elements play an important role. Therefore, the multi-agent attitude is appropriate, because it ensures:

- reduction in time necessary for the solution (thanks to the possibility of parallel and asynchronous procedures),
- elimination of demands on communication (specialized agents resolve their assignments and mutually interchange results of their actions),
- higher flexibility (the possibility to maintain the count of team agents),
- higher reliability (everyone is replaceable, the loss of one member does not threaten the operation of the whole system),
- lower costs regarding the fact that each component (agent) is simpler and therefore cheaper than the whole system (Štěpánková et al., 1997).

The disadvantages of such modelling comprising hardly quantifiable variables, the irrational behaviour of agents or subjective viewpoints should be obviously taken into account to eliminate potential consequences of their omission. Nevertheless, the advantages of the multi-agent approach utilization for biological and chemical incident management purposes prevail.

NetLogo model

The model utilized for the biological incident simulation is based on the multi-agent technology chosen regarding the afore-mentioned advantages of such approach and especially due to the character of incidents, where a lot of various factors with defined attributes and specific intended behaviour and interaction of autonomous agents emerge. Such modelling makes it possible to deal with the complexity of incident management. For these purposes, the NetLogo environment which can be downloaded for free is used (NetLogo, 2011). This environment allows the observation of natural and social phenomena as well as the modelling of complex systems which develop over time. Another advantage is the environment interactivity and flexibility which allows the input parameters setting and their adjustment. The user interface offers also the utilization of extensive dictionary of built-in constructs and mathematical operations (Olševičová, 2011). Furthermore, various output formats can be selected and a range of quite a few extensions is available including the addition of sound, access to MySQL databases or the connection to Geographic Information System. Considering the purpose of the simulation, which is to verify the technology and demonstrate the required functionality, the selected environment is adequate and sufficient.

RESULTS AND DISCUSSION

The simulation prototype of incident development can be perceived as an important part of the entire system for scenario creation providing the simulation of the agent spread within the environment. The aim is the evaluation of the incident impact on the population and the appropriate coordination of preventive countermeasures and eventually rescue works. The input comprises the subset of parameters embracing the up-to-date data about the environment and the domain knowledge about the certain agent derived from the elaborated ontology based on the semi-structured interviews with domain experts from fields of biology, medicine, and epidemiology. The outputs of simulation are values of particular parameters in a certain time.

Model description

There are few basic ways how the agent can be spread. The discussed prototype is primarily focused on the spread of the agent transmissible through the air. The agents are classified to these representing the population and the second group depicts the contaminated cloud. The described model is the analogy of the model called Virus available in the Biology section of the Models Library of the NetLogo (NetLogo, 2011). Nevertheless, the model is amended according to research aims and purposes. The detailed significant differences are observable while comparing Figs. 1 and 2. Fig. 1 shows the NetLogo model Virus which illustrates only the number of health, sick, and immune people. There is no influence of a cloud which supports the agent's spread among people. The climate conditions and options to amend the model are omitted. On the contrary, Fig. 2 demonstrates model based on author's research and includes the presence of a cloud of the infectious substance.

The entire model uses two layers. The first one represents the environment within which the simulation proceeds. The second layer embodies the people divided into two groups. At the beginning of the simulation, sick-count is set to 0, because only healthy persons are present. During the simulation progress, some healthy people become infected. In the case of death, the particular person disappears from the simulation. In addition to the initialization of people's characteristics, the rules determining their random movement within the environment are set. The people impacted by the contaminated cloud are infected regarding to the level of infectability. The infectability is the highest at incident location and decreases gradually with the distance from the incident location and the spread intensity.

As mentioned above, within the simulation there are also agents representing the particles of the contaminated cloud. The spread of a certain agent is characterized by particular parameters which comprise two interlinked phases. The initial phase represents the cloud expansion when its size grows according to the spread intensity. For the description of the cloud spread, the colour differentiation is utilized. The

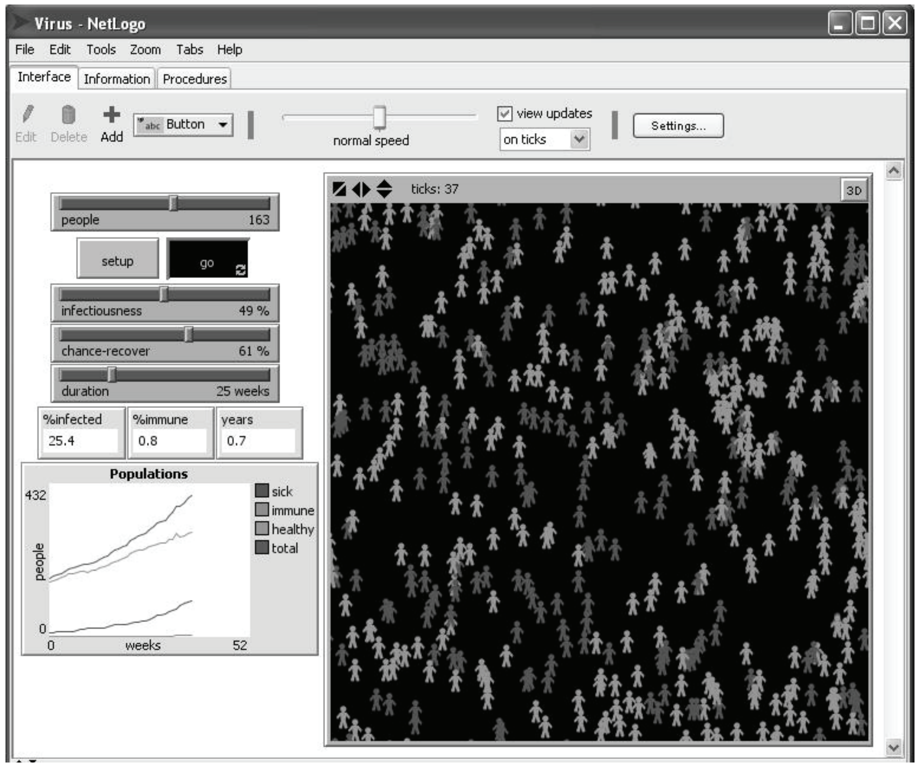

Fig. 1. The NetLogo model Virus (source: N e t L o g o , 2011)

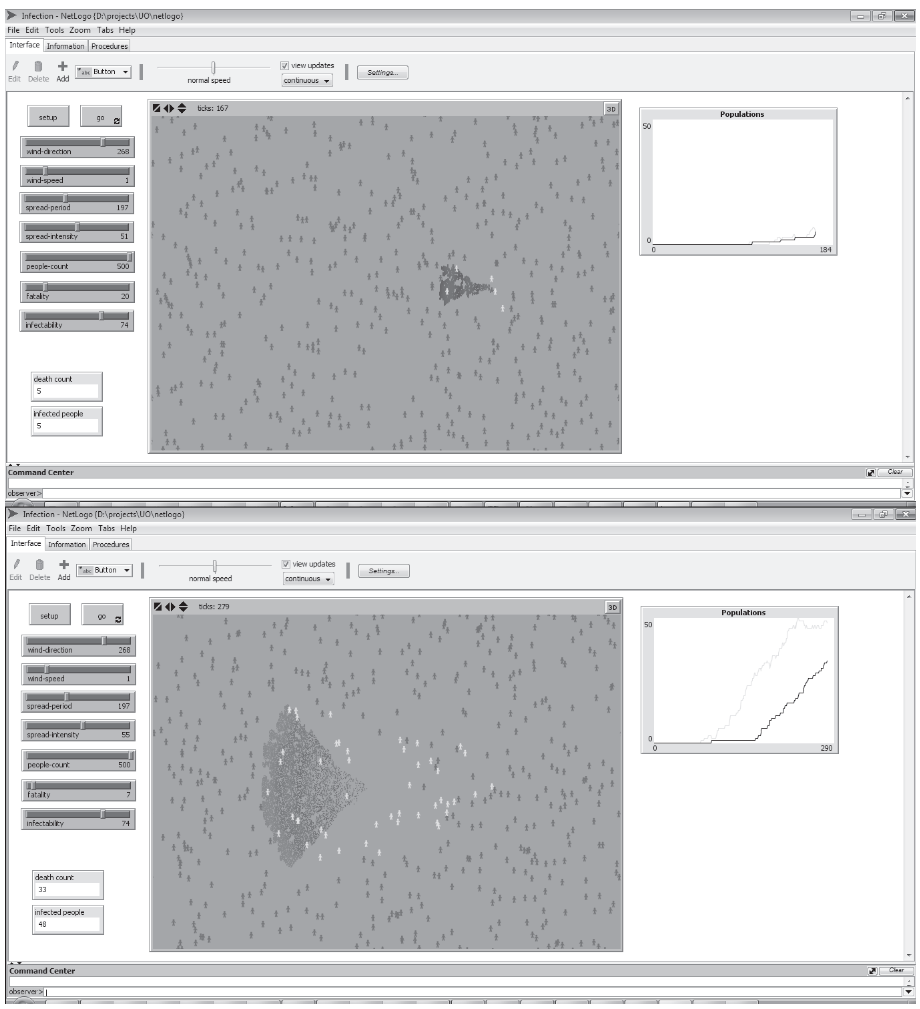

Fig. 2. Agent-based scenario development (source: authors)

colouring of the cells proceeds in the wind direction. Nevertheless, this process runs only in the case of cells in the neighbourhood of already coloured ones. Each time unit during the spread period, a cell at the angle of –45–+45° is randomly chosen and coloured. Within the later phase, the diffusion process prevails. The progressive spread of the harmful agent is observable. This process is logically separated also in the code. Nevertheless, during both phases the cloud moves according to the given wind speed and wind direction. The exemplification of a prototype describing the agents' spread is illustrated in Fig. 2. The infectability intensity is expressed by various colour shades of grey where darker shade represents higher intensity. The cloud is divided into two parts, the inside and the edge, where only the edge spreads. Progressively, the cloud moves according to the wind direction and its consecutive dispersion. Simultaneously, the number of infected and dead people increases reflecting the fatality of the given agent and/or according to the probability of the transmission from one person to another. The cloud movement is influenced not only by the climate, but in reality this phenomenon has partially a random character. Therefore, the inclusion of the possibility to set the share of actual climate conditions (wind speed and wind direction) and of random factors is relevant. In practice the climate conditions would have ordinarily higher impact (over 90%).

Parameterization

The parameters represent the input values of the simulation model. Therefore, especially because of the model accuracy and reliability, it is important to pay attention to their unambiguous determination. NetLogo offers the amendment of input parameters according to the user's needs and thereby provides us with the option to observe the agent's behaviour as well as environment changes under various conditions. For this particular simulation the following parameters with under-mentioned values are used. Obviously, these parameters are easily amendable for specific purposes of each incident.

- Wind direction: 0–360 degrees
- Wind speed: 0–10 points per time unit
- Spread period: 0–500 time units; time period of the cloud spread during the simulation
- Spread intensity: probability of the infection spread within the cloud further into the environment (the edge of the cloud)
- People count: 0–500
- Fatality: probability of death of an infected person (taken from appropriate resources, e.g. USAMRIID, 2011)
- Infectability: probability that the cloud infects a person.

Particular values of these parameters depend on the chosen agent. These are acquired from the modelled domain knowledge in subsystem modelling the incident compiled on the basis of data from the Committee on Toxicology (National Research Council, 1997). Moreover, the population size can be chosen and characteristics of the environment are adjustable. These noticeably influence the agents' spread. Especially, the weather and climate conditions in the impacted area are considered. Within the model, the parameters relating to wind are reflected.

Limitations and further research

The basic limitation is related to the size of population which can be selected from 0 to 500. Such extent is sufficient for the illustrative purposes of the simulation. Higher population size unnecessarily increases the demands on the computational complexity and proportionally decreases the simulation speed. This problem might be eliminated by the employment of various methods such as Parallel Computing (Panus, 2010). The model also does not work with data from real environment. The third layer representing a map of real area with objects that influence the agent spread or rules describing more realistic behaviour of the wind in such environment can be added. The improvement of the visualization can be ensured by the linkage to the density of defined population or maps from Geographic Information Systems. Furthermore, it is important to notify that the prototype described within this paper serves the purposes of technology verification and demonstration of its functionality in the context of the overall system depicted at the end of the Problem Formulation section.

The further research covers a lot of various items. First of all, precision and specification of the simulation can be reached employing the suitable epidemiological models of agent spread – e.g. see Ajelli et al. (2010), NetLogo (2011), O'Neil, Sattenspiel (2010). Furthermore, the real data acquired from relevant sources can be utilized for more accurate illustration of the actual situation. Among others, demographic data, strategic documents or medical and epidemiological systems are mentioned. Likewise, the inclusion of more parameters describing the environment especially in terms of weather conditions should be considered due to the importance of their influence on the incident development. Generally, it is possible to extend the amount and the details of the input parameters. However, this results in higher demands on the user, parameters' availability as well as format. The input data bear a certain level of fuzziness and vagueness and therefore the employment of fuzzy decision tables which decrease the level of imprecision and enhance the completeness and consistency of models (Vaníček, Vostrovský, 2008) might be considered. Moreover, the parameters should be optimized and prioritized according to the purpose of the model and their importance. For predicting

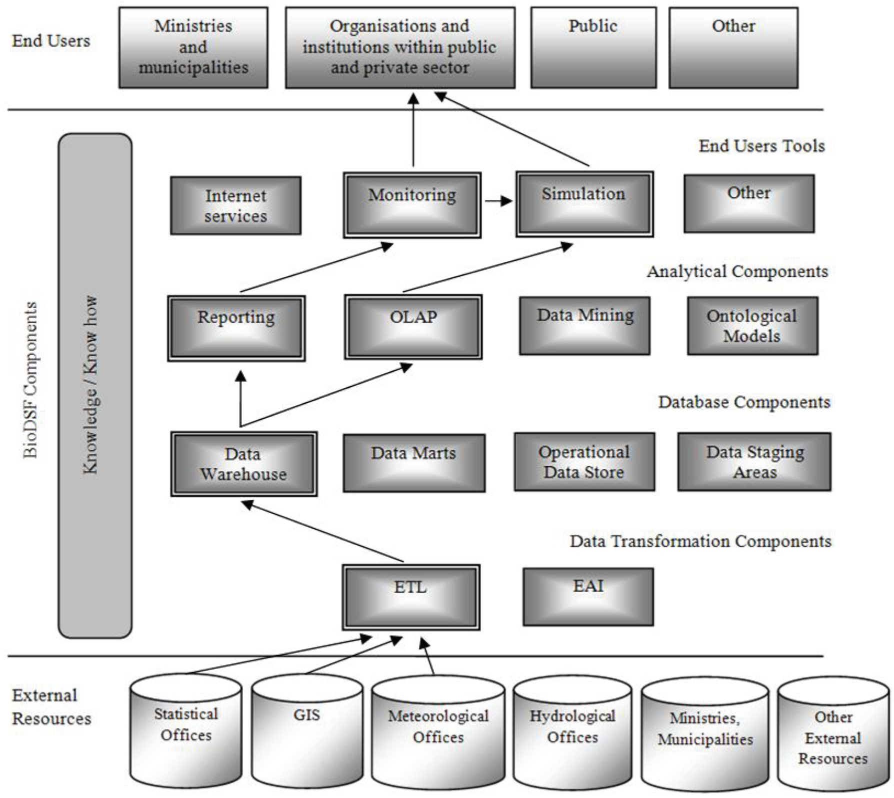

Fig. 3. The context of the simulation within the biological incident management (source: authors, adapted from N o v o t n ý et al., 2005)

the potential threats and consequences, ensuring the decision-making with lower risk and enhancing knowledge transfer, the Business Continuity Management might be employed to improve accuracy of the models (U r b a n c o v á, K ö n i g o v á, 2011).

Moreover, the connection of the model to other applications is possible. The general context of the simulation is illustrated in Fig. 3 which depicts the framework for the biological incident management with its potential components. The external resources are represented by the input data. Such data necessitate to be transformed into relevant and comprehensible information for the end users represented by the decision-makers. Therefore, the utilizable tools and methods for the data transformation and analysis mostly based on the principles of business intelligence (N o v o t n ý et al., 2005) are demonstrated. All the mentioned end users need to possess as precise information as possible. The simulation obviously influences and specifies both the course of action and the particular countermeasures they decide to take. The related trajectory of data and information flow is depicted in Fig. 3. Apparently, the data from resource databases are gathered with help of ETL (Extract, Transformation, Load) tools to the Data Warehouse, from which they can be used for either periodical reporting, or *ad hoc* inquiring. Regular reports provide the simulation model with initial setting of parameters, while *ad hoc* inquiries are used for what-if analysis. Hence, the utilization of online analytical processing (OLAP) providing fast data analysis and prompt response to given questions can be included. This should provide even quicker and more precise decisions leading.

The simulation can be also connected with other systems. For instance, the web-based applications can be useful. These might be based on the client-server architecture, where the database and application logic are available on a server, while the presentation layer is continually available for all users online. This is one of the main advantages of web applications in comparison with the desktop ones. Furthermore, subsequent improvement lies in mobile services which provide potential access to predefined analyses and other valuable outputs for mobile clients and facilitate the utilization of these processes out of office.

CONCLUSION

Biological or chemical incidents remain an unstructured and very complex issue. Considering the increasing value of impacted assets and growing demands on people who make decision under pressure with limited resources and cognitive skills, the readiness for the incident management needs to be supported. It has been already proved by research results that the computer-based scenario simulations, if correctly managed and interpreted, represent a useful tool for decision support during such situations. This is the reason why the most significant contribution of this paper should not be seen in the simulation model itself but in the decision-making processes that need to be supported. These processes have usually the form of tacit or implicit knowledge of experts in epidemiology or toxicology. Their inclusion into the used simulation models makes these processes more explicit and utilizable for non-experts in agriculture or industrial realm. Consequently, it moves the area of biological or chemical incident management to further level of maturity of the model, which should be more easily managed and eventually prepared for optimization for the decision makers (Paulk et al., 1995). Therefore, the discussed multi-agent based technology can be recommended and employed to improve the impact elimination, resource planning or future preparedness for similar incidents.

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